

MAN-MADE NOISE IN THE 136 to 138-MHz VHF METEOROLOGICAL SATELLITE BAND

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Satellite radio system performance in the 136 to 138-MHz VHF meteorological satellite band is compromised by man-made noise external to the receiver. Methods used for predicting man-made noise power in this band are based on measurements conducted in the 1970's. These methods may be inaccurate due to technological advances such as quieter automotive ignition systems and the proliferation of consumer electronic devices such as the personal computer. This report describes noise power measurements the Institute for Telecommunication Sciences performed in the 136 to 138-MHz VHF meteorological satellite band. Statistics of average noise power were compared to those of measurements conducted in the 1970's. The noise power measurements were also used to model instantaneous noise power for simulation of radio links.

Key words: radio channel, man-made noise, impulsive noise, non-Gaussian noise, meteorological satellite, satellite communications, simulation of communication systems, noise measurement, noise modeling.

1. INTRODUCTION

In 1974, Spaulding and Disney [1] presented results that summarized many years of measurements of radio noise - both natural and man-made. From these results they devised methods for estimating the noise power statistics that are important in the design of radio systems. These methods are described in the CCIR Reports [2,3] and have been widely used by industry. Figure 1.1, taken from these reports, presents the median antenna noise figure (a measure of the environment's average noise power) from 0.1 to 1000.0 MHz. The graph shows that contributions in the 136 to 138-MHz VHF meteorological satellite band by atmospheric noise (distant lightning) or galactic sources are minimal, and that man-made noise in business, residential, or rural environments might be significant.

In recent reports, Spaulding [4,5] has warned that the CCIR methods - at least when referring to man-made noise - may have been made inaccurate by technological advances. For example, newer automobile ignition systems radiate less noise, but personal computers capable of producing considerable noise have become ubiquitous in business and residential environments. Thus, measurement and modeling of man-made noise is timely for the design of VHF meteorological satellite radio systems [6,7].

We began our noise power measurement and modeling campaign by building a noise power measurement receiver and writing computer software that digitized and stored noise power samples

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for later analysis. The receiver and computer were installed in a van that was driven to rural, residential, and business environments for data collection. We also attempted to isolate noise power generated by automobiles, the electrical distribution network, and electronic devices.

The data, stored in histograms representing two minutes of noise power samples, were analyzed in two distinct ways. First, the statistical behavior of each histogram's average power was analyzed for rural, residential, and business environments. Second, the first-order statistics of instantaneous noise power within a histogram were studied. Algorithms capable of generating noise with similar first-order statistics were then created for simulation of radio links.

This section continues with a review of the terminology used to describe radio noise. Section 2 describes the noise measurement equipment. Section 3 gives an overview of the measurements taken. Section 4 summarizes the average noise power in rural, residential, and business environments. Section 5 analyzes first-order statistics of instantaneous noise power and presents a discrete noise model for simulation of radio links. Section 6 summarizes our findings.

1.1. Background and Terminology

1.1.1 Noise Voltage Representations

A noise voltage is a random function of time whose behavior only can be described statistically. The time-varying noise voltage, $v(t)$, is represented as a *passband* signal centered about a carrier frequency, f_c ,

$$v(t) = \text{Re}\left\{\hat{v}(t)e^{j2\pi f_c t}\right\}, \quad (1.1)$$

where $\text{Re}\{\}$ denotes the real part and $\hat{v}(t)$ is the noise voltage *complex baseband* signal centered about 0 Hz that can be represented in Cartesian or polar form as follows:

$$\hat{v}(t) = x(t) + jy(t) = \sqrt{x(t)^2 + y(t)^2} e^{j \arctan\left(\frac{y(t)}{x(t)}\right)}. \quad (1.2)$$

where $x(t)$ and $y(t)$ are the baseband signal real and imaginary components, respectively. Both $v(t)$ and $\hat{v}(t)$ are random processes defined by one or more random variables. For example, if $v(t)$ is *white Gaussian noise* it is represented by a *Gaussian distributed* random variable whose mean is zero and *power spectral density* (PSD) is flat. The baseband real and imaginary components of white Gaussian noise are *independent and identically distributed* Gaussian random variables with zero means and flat PSD's. The baseband amplitude and phase of white Gaussian noise are independent but not identically distributed random variables. The amplitude random variable is *Rayleigh distributed* while the phase random variable is *uniformly distributed*.

1.1.2 Instantaneous Noise Power

We define the *instantaneous noise power* as

$$w = |\hat{v}(t)|^2 . \quad (1.3)$$

In this report the instantaneous noise power is normalized by the average noise power due to black-body radiation and thermal noise that is present in all radio systems. This average noise power is kT_0b where $k = 1.38 \times 10^{-23}$ W/Hz/K is Boltzman's constant, $T_0 = 288$ K is the absolute temperature, and b is the receiver *noise equivalent bandwidth*.

1.1.3 Statistics of Instantaneous Noise Power

The *cumulative distribution function (CDF)* of instantaneous noise power describes the probability that the noise power will not exceed a value

$$P(W_{RV} \leq w) = \int_0^w p(x) dx , \quad (1.4)$$

where W_{RV} is the noise power random variable, w is the noise power independent variable, and $p(w)$ is the *probability density function (PDF)* of the noise power random variable. Radio engineers are concerned with the probability that the noise power will exceed a value. This probability is expressed as

$$A(w) = P(W_{RV} > w) = \int_w^\infty p(x) dx \quad (1.5)$$

and is customarily referred to as the *amplitude probability distribution function (APD)*.

For white Gaussian noise, the amplitude PDF, expressed in w , is

$$P(w) = \frac{1}{w_0} e^{-\frac{w}{w_0}} , \quad (1.6)$$

the amplitude CDF, expressed in w , is

$$P(W_{RV} \leq w) = 1 - e^{-\frac{w}{w_0}} , \quad (1.7)$$

and the APD, expressed in w , is

$$A(w) = P(W_{RV} > w) = e^{-\frac{w}{w_0}}. \quad (1.8)$$

In this report APD's are plotted on a *Rayleigh probability graph* whose axes represent the amplitude in dB above kT_0b and the percent of time the amplitude is exceeded. On a Rayleigh probability graph, noise with a Rayleigh amplitude distribution forms a straight line with slope -1/2 whose mean lies on the 37.0 percentile, median lies on the 50.0 percentile, and peak (as defined in this report) lies on the 0.01 percentile. The median of the Rayleigh amplitude distribution is 1.6 dB below the mean while the peak is 9.6 dB above the mean. Impulsive noise is represented by amplitudes that exceed this line at low probabilities and continuous wave interference is represented by an approximately straight line with a slope that approaches zero as the continuous wave power to Gaussian noise power ratio increases.

1.1.4 Average Noise Power

White Gaussian noise is completely described by its variance, which is equivalent to the average noise power. The average noise power is vitally important for non-Gaussian noise also. The *average noise power* is defined as

$$w_0 = E\{w\} \quad (1.9)$$

where $E\{\}$ denotes the expected value of its argument. The *average noise power* relative to kT_0b is called the *noise factor* and is given by

$$f = \frac{w_0}{kT_0b}, \quad (1.10)$$

and the *noise figure* in dB is

$$F = 10 \log_{10} f. \quad (1.11)$$

1.1.5 Antenna Noise Factors

The noise collected by the antenna originates, presumably, from widely scattered directions at or near the horizon and is therefore altered by the receiving station antenna directional gain. If $S(2, N)$ is the power density coming from elevation 2 and azimuth N , and $g(2, N)$ is the antenna directional gain relative to isotropic, then the total noise power received by an antenna is

$$w_a = \frac{\lambda^2}{4\pi} \int_0^{2\pi} \int_{-\pi/2}^{\pi/2} S(\theta, \phi) g(\theta, \phi) \cos(\theta) d\theta d\phi \quad (1.12)$$

where λ is the wavelength. The corresponding antenna noise factor is

$$f_a = \frac{E\{w_a\}}{kT_0 b} . \quad (1.13)$$

A noise power measurement system consists of an antenna, antenna matching circuit, transmission line, and receiver. If the antenna matching circuit and transmission line are assumed to be lossless and operating at a temperature T_0 , the measured noise factor is related to the antenna noise factor and receiver noise factor by

$$f_a = f - f_r + 1 \quad (1.14)$$

where f is the measured noise factor and f_r is the receiver noise factor. The corresponding antenna noise figure, the principle quantity used by radio system designers, is

$$F_a = 10 \log_{10} f_a . \quad (1.15)$$

1.1.6 Statistics of Antenna Noise Figure

The statistical behavior of F_a can be shown by plotting the distribution on a *normal probability graph* where random variables that are Gaussian distributed form a straight line with a slope equal to its standard deviation and a median equal to its mean. The graph is used to determine the median antenna noise figure F_{am} of a *rural, residential, or business environment*. Further analysis of F_a includes determining *within-the-hour-, hour-to-hour-, and location-to-location-variability*.

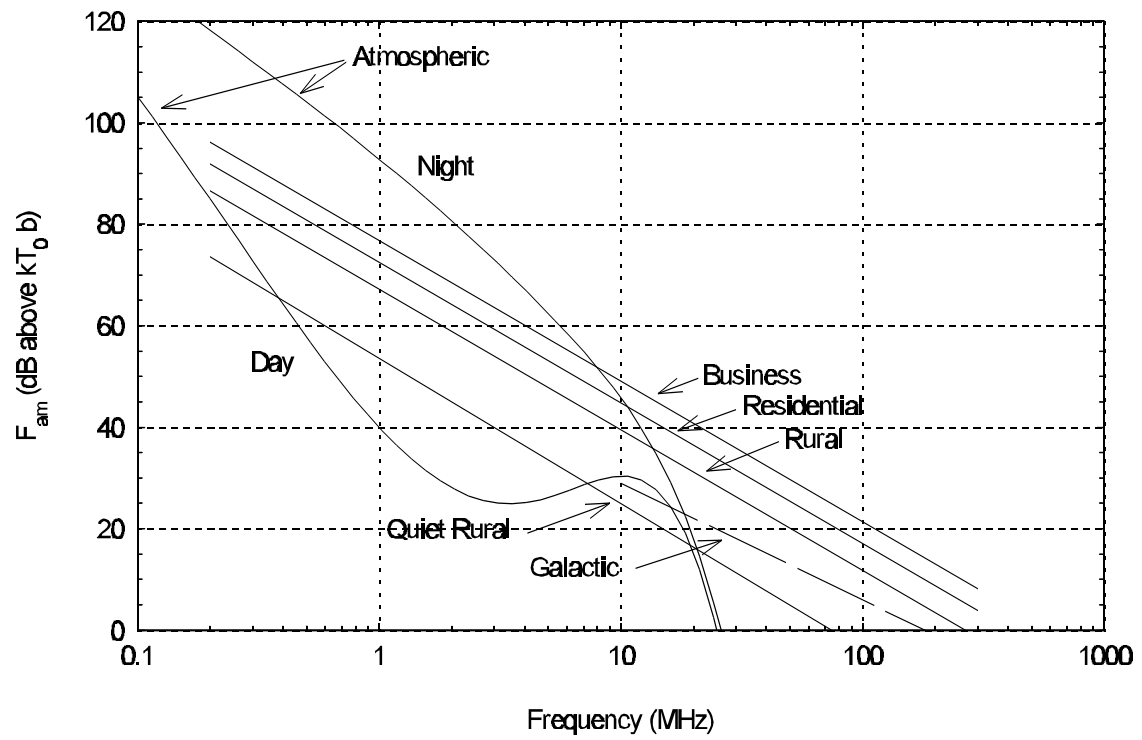


Figure 1.1 Median values of F_a